Development of a High Count Rate Gaseous Neutron Detector

	もはまど　なほすてぃん
氏　　　　　名	モハマド　ナホスティン
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指　導　教　員	東北大学教授　馬場　護
論文審査委員	主査　東北大学教授　馬場　護　　東北大学教授　笹尾　真実子 東北大学教授　山崎　浩道　東北大学准教授　寺川　貴樹 東北大学准教授　松山　成男

論文内容要旨

In recent years, great developments have been made in several fields of nuclear science and technology by which extreme requirements are imposed on the neutron detectors. Two prominent examples of such fields are the spallation neutron facilities and fusion technology. In the advanced spallation neutron facilities like the Spallation Neutron Source (SNS) facility in United States, the J-PARC project in Japan and the ISIS second target station project in United Kingdom the neutron intensity will be an order of magnitude brighter than the most powerful facilities that are operating now, and these improvements in brightness will make possible many new areas of research which require neutron detectors of high performance. Also, in fusion technology, neutron detection and neutron spectrometry provide the fusion community with a reliable set of diagnostic tools. For example, the neutron emission rate and distribution provide information about the plasma's reaction rate and spatial distribution and the detailed spectral shape near 14.1 MeV provides information about the ion temperature and the degree to which reaction products have been incorporated in the plasma. Clearly, for exploiting such information from a burning plasma appropriate neutron detectors are of vital importance.

Unfortunately, in respect to the above-mentioned applications, the traditional neutron detectors have several limitations. The main limitation is the counting rate capability. The counting rate of traditional neutron detectors is limited to several hundred of kHz while in the new applications, counting rates in MHz region are demanded. Moreover, the available neutron detectors fail to fulfill the requirements concerning the total coverage surface, time resolution and γ-insensitivity. Therefore, for instrumentation in the new facilities, substantial improvements over the present standards of neutron detectors are indispensable.

This thesis concerns with the development of new gaseous detectors with improved count rate capability, gamma insensitivity, time resolution and possibility of construction in large sensitive area. Gaseous detectors with parallel-plate structure like parallel-plate avalanche counter (PPAC) and its evolution, Micromegas have been considered as a platform for the developments. PPAC was selected due to its excellent timing properties, very low sensitivity to gamma rays and its potential for construction in large sensitive area. Furthermore, count rate capability of PPAC is much higher than that of wire chambers. With respect to Micromegas, the detector was selected due to its high rate capability, good time and space resolution. To develop the new detectors, the following steps have been undertaken:

- A detailed study was performed on the gas amplification process in the parallel-plate avalanche counters (PPACs). Generally, in detectors operating under gas amplification, the gas amplification is determined by the first Townsend coefficient and therefore its precise measurement is required for development of gaseous detectors. The study was carried out using iso-C_4H_{10} gas which is the common gas for low-pressure counters. The results obtained in this work are free from space charge and gap deformation effects, which have seriously affected previous PPAC-based measurements. The required conditions for a reliable measurement of First Townsend coefficient are presented as well.
- A fast (14-MeV) neutron detector with high time-resolution was developed which is particularly suitable for TOF measurement in applications such as fusion technology. The detector is based on the combination of PPAC with a sheet of polypropylene as fast neutron-to-charged particle converter. By employing a carefully shielded chamber, neutron induced charged particles background from the chamber body was successfully reduced to less than 6×10^{-5} count per incident neutron. Fast signals with ~ 7 nanosecond rise-time were

observed. A satisfactory signal-to-noise ratio was obtained by a stack structure of several PPACs. A very low sensitivity to gamma rays is another advantage of this detector.

- A slow-neutron detector based on avalanche counter was developed. The choice of a suitable neutron converter is discussed on the basis of Monte Carlo simulation and some experimental results are shown. Excellent γ-insensitivity, high rate capability, possibility of construction in large sensitive area and low production cost are among the promising features of this neutron detector.
- The digital signal processing (DSP) technique as a new and powerful method of data acquisition was employed for the extraction of the timing properties of the PPAC. The results of this part of the thesis are particularly important for development of new data acquisition systems. The preamplifier output signals of two identical avalanche counters were simultaneously digitized with different sampling rate up to 10 GS/s and post processed. The post processing includes signal/noise discrimination, noise filtration and time pick-off process. A time resolution better than 400 ps was obtained which matches the best literature results using analog electronics.
- A new version of the high rate gaseous detector based on low-pressure Micromegas detector was developed. The details of detector design, construction and test experiments results with α-source and ^{252}Cf neutron source are presented. The detector operates at low gas pressures (5-50 Torr) which allow to use larger amplification gap than in the standard Micromegas detectors. With detectors having 200 of amplification gap short signal with 100 ns duration were observed. The energy resolution of the detector is 14%. In comparison with the standard Micromegas neutron detectors, the detector allows the possibility of construction in larger areas owing to its larger gaps, very low sensitivity to gamma rays and simple construction. The detector is a very attractive option not only for neutrons but also for charged particles detection in intense accelerators.
- The energy resolution of avalanche counters was explored. This study is interesting not only from applied purposes but also from a cognitive point of view. The author showed that the energy resolution of PPAC is explained as a result of two kinds of fluctuation resulting from

energy loss and electron avalanche multiplication.

論文審査結果の要旨

現在開発が進められている核破砕中性子源や核融合実験炉においては，大強度の中性子束から限られた時間内に強度，エネルギー，空間分布を求めることが必要とされ，そのため，高計数率に耐えうる中性子検出器が求められている。中性子にはγ線が不可避的に伴うため，中性子カウンターにはγ線が除去できるか弁別できること，更に耐放射線損傷を有することも求められる。

本論文はこれらの条件を満たすものとして，平行平板雪崩ガス検出器(PPAC)に着目し，放電特性に係わる基礎的特性を明らかにするとともに，陽子やα粒子など軽荷電粒子を用いたPPAC型中性子検出器を初めて実用化したもので，全6章からなる。

第1章は序論であり，研究の背景と目的，研究の方法の概要を述べている。

第2章では，PPAC型検出器に関する知見をまとめ，研究の方向付けを行っている。

第3章では，PPAC検出器さらにはガス放電現象一般の基礎となるものでありながらよく分かっていないタウンゼント係数を、PPACを用いて精度良く測定する手法を考案し，これを用いて，高い精度のデータを取得している。また，デジタル信号処理手法を用いて，PPACの時間応答や波高特性の詳細に明らかにしている。これらはPPACと特性を理解し発展させるための重要な手がかりとなるものである。

第4章では，PPACを用いた中性子検出器の開発について述べている。高速中性子に対しては中性子を荷電粒子に変換するコンバータに，ポリエチレン箔を用い，ガス圧の適正化と高Z核材料を検出器窓，容器壁に用いることによって，14MeV中性子に対しても十分な信号対バックグラウンド比の反跳陽子型中性子検出器を実現している。低速中性子に対しては ^{6}LFをコンバータに用いることで，PPAC中性子検出器を開発している。これら軽荷電粒子に対しても300ps程度の高時間分解能と10ns程度の高速応答を確認している。これらは，核分裂物質を用いないPPAC中性子検出器を実現した点で重要であり，検出器の利用範囲を拡大するのに寄与すると期待される。

第5章では，中性子の荷電粒子への変換と放電・増倍のための領域を分離することによってPPACのエネルギー分解能の向上を図るマイクロメガ中性子検出器に着目し，動作圧を下げることによって堅牢で安定な検出器が可能となることを示している。これによって，～10^7 カウント/秒の高速応答と比較的良好なエネルギー分解能を両立させる手法を実用化した意義は大きい。

第6章では，研究の総括として各章で得られた知見をとりまとめている。

以上要するに本論文は，PPACにおける放電特性を解明すると共に中性子用の位置敏感型 PPAC，マイクロメガ型など 10^7 カウント/秒 以上の高速計数を可能とするガス型中性子検出器を開発したもので，量子エネルギー工学の発展に寄与するところ少なくない。

よって，本論文は博士(工学)の学位論文として合格と認める。